LOW TEMPERATURE OPERATION OF BATTERIES

QUARTERLY REPORT NO. 3

SIGNAL CORPS
CONTRACT NO. DA36-039-SC-90706

DEPARTMENT OF ARMY
PROJECT 3A99 09-002-02

THIRD QUARTERLY PROGRESS REPORT
15 November 1962 to 14 February 1963

U. S. ARMY ELECTRONICS RESEARCH AND DEVELOPMENT LABORATORY
FT. MONMOUTH, NEW JERSEY

ARTHUR D. LITTLE, INC.

LOW TEMPERATURE OPERATION OF BATTERIES

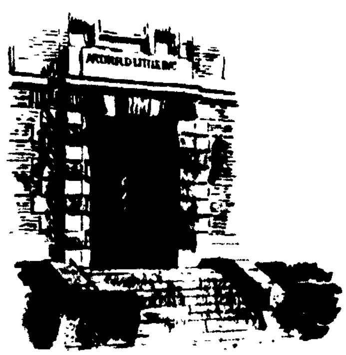
Quarterly Report Number 3

Signal Corps
Contract No. DA36-039-SC-90706

Department of Army
Project 3A99 09-002-02

Third Quarterly Progress Report
15 November 1962 to 14 February 1963

U. S. Army Electronics Research and Development
Laboratory
Ft. Monmouth, New Jersey



Arthur D. Little, Inc.

LOW TEMPERATURE OPERATION OF BATTERIES

Quarterly Report Number 3

Signal Corps
Contract No. DA36-039-SC-90706

Department of Army
Project 3A99 09-002-02

Third Quarterly Progress Report
15 November 1962 to 14 February 1963

OBJECT: To determine the most satisfactory methods of achieving low temperature operation of batteries under conditions of military use.

Report prepared by:

R. A. Horne

I. A. Black

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

PURPOSE

The purpose of the present work is to conduct studies that will provide for a comprehensive, comparative evaluation of electrochemical systems and methods which have been used, or which could be used effectively to provide battery performance in an ambient temperature range of -40°F to -65°F.

ABSTRACT

Reported values for watt-hr/lb, in^3/lb, and $/lb have been assembled for primary and secondary batteries for the temperature range +70 to -65°F. The specific heat and thermal diffusivity of the BA-270/U battery has been measured. The heat leak through electrical leads has been analyzed. A computer program has been prepared for calculating the time-temperature history of battery-heater-insulation systems.

<u>CONFERENCES</u>

On February 11, 1963, USAELRDL, Ft. Monmouth, N.J.

Present:	J. M. Hovendon D. Linden	Electronics R&D Lab
	I. A. Black R. A. Horne	Arthur D. Little, Inc.

Topics of the discussion included: a) revision of the Second Quarterly Report, b) the relationship between the quarterly and the final reports, c) the proper level of detail in the reports, d) the proper amount of treatment of the less promising systems in the reports, e) the breadth and generality of the work, in particular an extension of interest to short missions and high discharge rates, f) the rate of expenditures (the rate is now at projected level but, due to an initial labor shortage, the total expenditure is behind schedule--a three month time extension of the present work was suggested to compensate for this lag), g) the computer program, h) future effort.

On March 5, 1963, Arthur D. Little, Inc., Cambridge

Present:	M. D. Aiken	U.S.Army Materiel Command
	R. A. Horne I. A. Black D. L. Richardson	Arthur D. Little, Inc.

Discussion of Arctic operation battery consumption and the insulating and heating of a Ni-Cd aircraft start-up battery.

On January 22, 1963, Dr. G. S. Lozier of the Radio Corporation of America addressed the Boston Section of the Electrochemical Society. We took advantage of the occasion by inviting him to visit ADL, Cambridge, prior to the meeting for the purpose of discussing the low temperature performance of the magnesium cells which he is developing. Among the topics discussed were activation, low temperature performance data, future cost, delayed action, heat production, major anode processes, low drain rates and avoidance of electrolyte freezing and boiling.

INTRODUCTION

In the Second Quarter, heater performance information was assembled; in the Third Quarter battery performance data over the range +70 to -65°F were assembled. The insulation studies begun earlier have been continued in the Third Quarter. Specifically, information concerning the thermal properties of batteries has been obtained, heat loss through battery leads has been examined, and a computer program has been designed which will enable us to treat the thermal life-history of a battery-heater-insulation system in a general manner.

LOW TEMPERATURE PERFORMANCE OF BATTERIES

Reported values for the parameter watt-hr/lb are being collected for all primary and secondary batteries for which reliable low temperature performance data are available and tabulated for the temperatures +70, +32, 0, -20, -40, and -65°F. Inasmuch as this information is taken from a variety of sources there is no uniformity in the way in which the measurements were made; therefore, we have been unable to make direct comparisons among different types of battery. This difficulty has been circumvented by comparing the performance of the different batteries for operation within the following current drain ranges:

Range I	0.1 to 2 amps and greater
Range II	0.01 to 0.1 amp
Range III	0.001 to 0.01 amp

A tabulation of the temperature- and current drain-independent parameters in^3/lb and, whenever possible, $/lb is also being made for all types of batteries for which information is available. These tabulations will be reported in detail in the Final Report.

In addition to assembling and tabulating the above parameters, special problems relevant to the low temperature operation of particular batteries are being examined. These problems will be discussed in the Final Report.

INSULATION OF BATTERIES

I

Summary

This section describes our continuing effort to determine experimentally the performance of thermally insulated batteries which have provision for addition of electrical heat in order to maintain desired temperature levels. One combination of battery and insulation was investigated in an environment of -65°F. The specific heat and the thermal diffusivity of the BA-270/U battery were determined experimentally and compared with existing data. An analysis was made to determine the minimum heat leak through the battery leads and the optimum lead length. A generalized detailed analysis was prepared for an IBM 7040 computer to determine the time-temperature history of a battery-heater-insulation system. With this program, a parametric study will be made of the effects of battery geometry and thermal properties, insulation thickness and thermal properties, ambient temperature and convection, initial battery conditions, and both heat input and heat leaks.

II

Test Programs

A. Evaluation of Battery Insulation Performance

A container was fabricated to evaluate the thermal capabilities of non-evacuated glass paper insulations and to obtain data on the required electrical input heat necessary to maintain battery temperatures at approximately 70°, 40° and 0°F with all components in an ambient temperature of -65°F. The container shown in Figures 1 and 2 was fabricated from two clear plastic tubes each capped at one end. The inner tube was just large enough in diameter to contain the BA-270/U battery. The outer tube was large enough to allow a 1-inch thickness of .016 glass paper (approximately 60 layers) wrapped on the inner tube. A styrofoam plug 6-inches long was used to insulate the open end. Thermocouple and heater wire leads were directed out of the container by way of a long path in order to reduce the heat leak. Thermocouples were placed in the battery in the manner outlined in the Second Quarterly Progress Report.

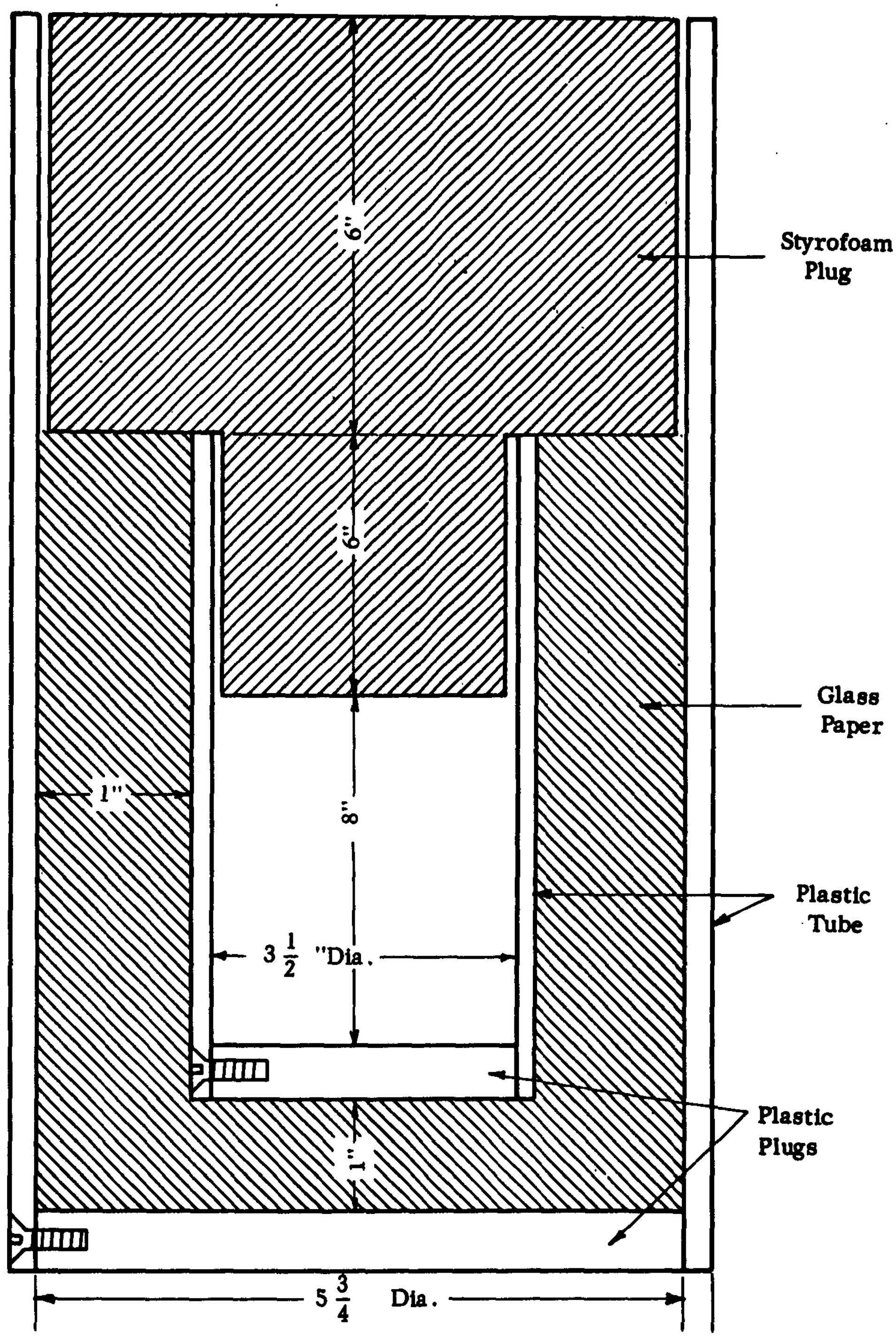


FIGURE 1 NONEVALUATED INSULATION CHAMBER

FIGURE 2 INSULATION CHAMBER AND INSTRUMENTED BATTERY

The conditions for all tests are summarized in Table I. Included in Table I are computed values of steady-state heat loss through the insulation system used in these tests.

1. Tests - Series 4

In these tests the battery and insulation were placed in the cold test chamber. Heat was applied to the battery by means of a 25 ohm heater wrapped closely around the battery surface. Sufficient power was applied to maintain the battery at a temperature of 97°F. When steady-state conditions were achieved, the power input was measured and the power was shut off. Temperature and time readings were then recorded until the battery temperature dropped to 62°F at which time the heat was again turned on. Sufficient power was supplied to stabilize the battery at a temperature of 62°F. Again the power was measured, shut off and the temperature-time measurements were resumed. In this manner, three steady-state operating conditions were achieved and the upper cooling curve of Figure 3 was generated.

2. Tests - Series 8

The heater configuration and location were changed from around the battery to the inside of the inner plastic tube and tests were made to determine whether the heater location would affect the slope of the cooling curve. These tests (series 8 on Table I) are summarized by the lower curve on Figure 3. It is apparent that the position of the heater had little effect on the slope of the cooling curves.

3. Steady-State Tests - Nos. 5-7

The steady-state tests are a continuation of work reported in the Second Quarterly Progress Report. In these tests the steady-state heat input requirements were determined for ambient conditions of -40, -20 and +3°F. All steady-state performances are summarized in Figure 4. The curve in Figure 4 is the calculated heat loss from the insulation system. The close agreement between calculated heat loss and measured heat input at steady-state conditions suggests that further testing is unnecessary.

Table I

SUMMARY OF BATTERY TESTS

Test Battery: BA-270/U
Insulation: 1-inch glass paper .016 thick - 60 layers
Container: Two clear plastic tubes:
inner tube - 3-1/2" I.D. x 1/8" wall
outer tube - 5-3/4" I.D. x 1/8" wall

Test No.	Type of Test	Ambient Temp °F	Battery Temp °F	Electric Heater Configuration	Measured Heat Input (watts)	Calculated Heat Loss (watts)
4A	Steady State	-70	97	25 ohm strip heater wrapped around battery	7.32	7.31
4B	Cooling of Battery	-70	See Fig. No. 2		none	
4C	Steady State	-70	62	same	5.06	5.8
4D	Cooling of Battery	-70	See Fig. No. 2		none	
4E	Steady State	-70	36	same	4.14	4.65
4F	Cooling of Battery	-70	See Fig. No. 2		none	
5	Steady State	-40	70	same	4.32	4.82
6	Steady State	-20	67	same	3.44	3.84
7	Steady State	+ 3	56	same	2.31	2.32
8A	Steady State	-62	73	39 ohm strip heater rolled on a mylar cylinder heater which fits against the inner wall of the inner plastic tube. Heater is away from battery.	6.42	5.9
8B	Cooling of Battery	-62	See Fig. No. 3		none	
8C	Steady State	-64	50	same	4.9	5
8D	Cooling of Battery	-64	See Fig. No. 3		none	

Table I (Continued)

Test No.	Type of Test	Ambient Temp °F	Battery Temp °F	Electric Heater Configuration	Measured Heat Input (watts)	Calculated Heat Loss (watts)
8E	Steady State	-62	31	39 ohm strip heater rolled on a mylar cylinder heater which fits against the inner wall of the inner plastic tube. Heater is away from battery.	4.27	4.06
8F	Cooling of Battery	-65	See Fig. No. 3		none	
8G	Steady State	-63	-4.5	same	2.5	2.56
8H	Cooling of Battery	-63	See Fig. No. 3		none	
8I	Steady State	-65	-47	same	1.02	.785
8J	Cooling of Battery	-65	See Fig. No. 3		none	

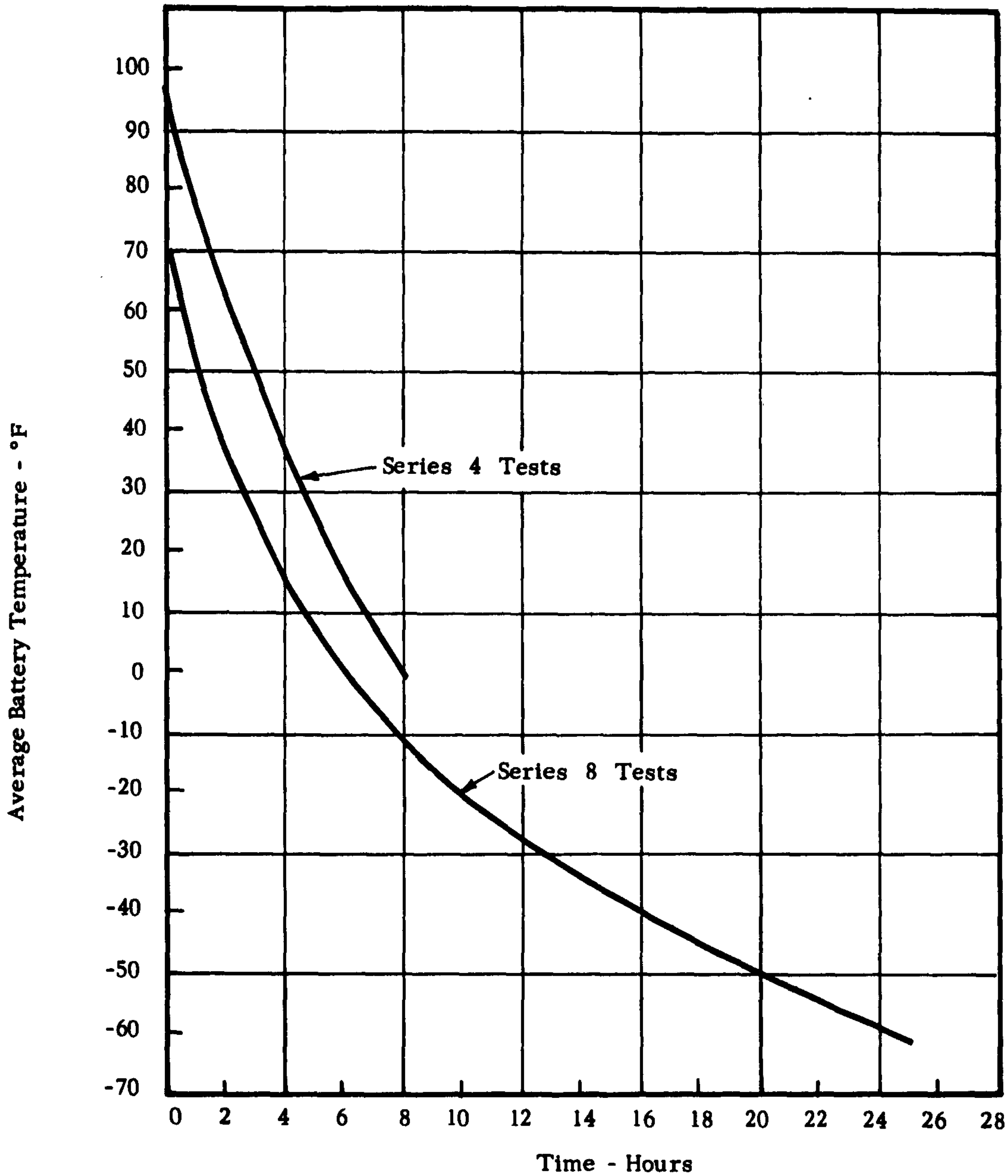


FIGURE 3 BATTERY COOL - DOWN PERFORMANCE

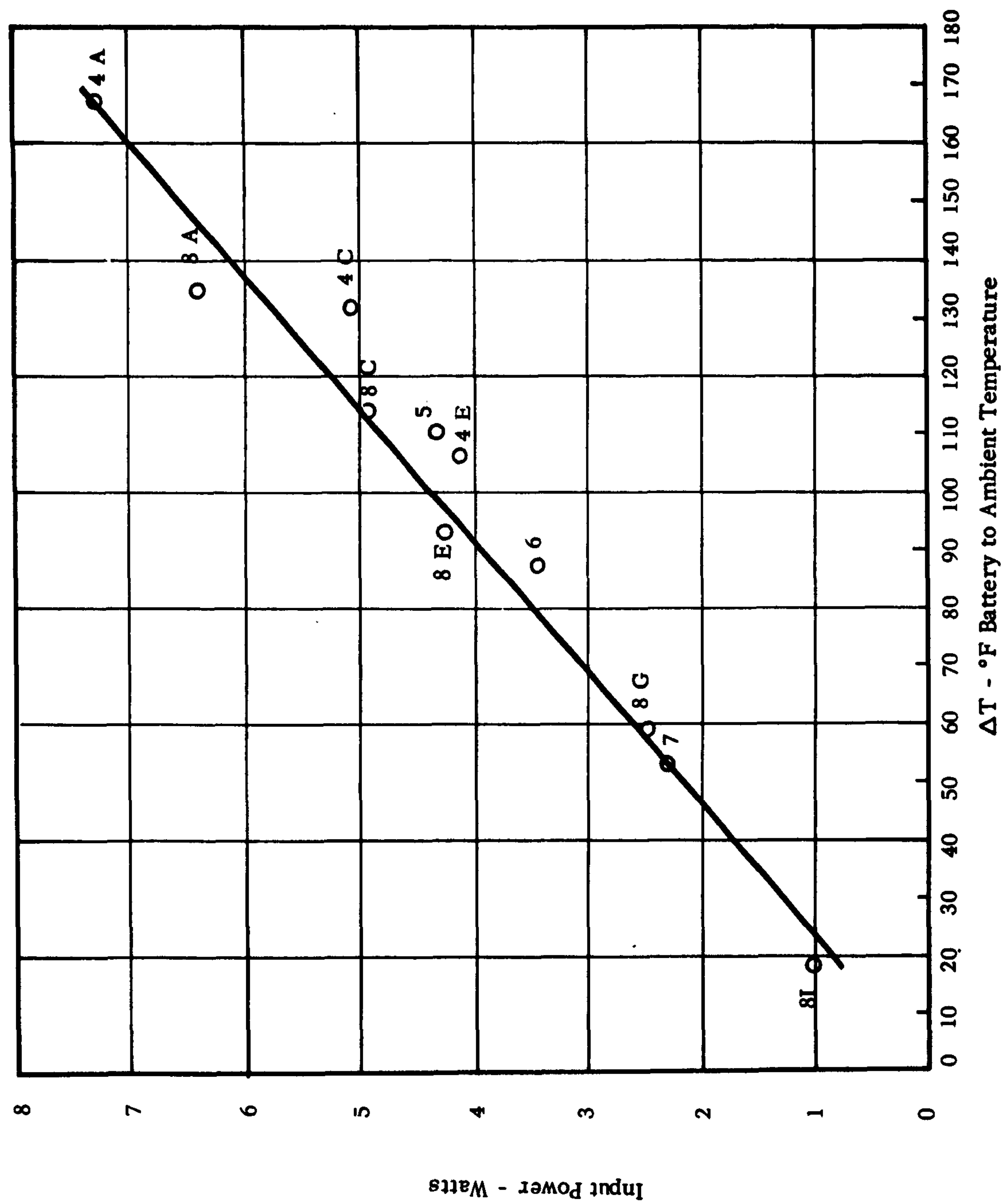


FIGURE 4 STEADY STATE INPUT VS. BATTERY TO AMBIENT TEMPERATURE DIFFERENCE

B. Thermal Properties of Batteries

1. Specific Heat

Calorimetric tests were made on Battery BA-270/U in order to determine its specific heat. The apparatus is shown in Figure 5. A conventional approach was used where the test sample (the battery) of known mass was heated throughout to a constant temperature (approximately 100°F). The calorimeter was a glass dewar 5-7/8-inches in diameter and 11-inches long which was partially filled with water cooled to near 32°F. A small agitator was employed to keep the water and dewar wall temperature uniform throughout the test. After all conditions had stabilized the heated battery was lowered into the cool water and the temperature rise of the water was noted.

Two calibration tests were made to determine the thermal constants of the dewar and to determine the heat flux from the atmosphere. In the first test, cold water was allowed to warm due to thermal flux from the ambient alone in order to determine the normal temperature rise of the apparatus; in the second test a block of aluminum of known mass and specific heat was used to calibrate the apparatus. Using the data from the calibration tests the specific heat of the battery was found to be 0.285 ± 0.020 Btu/lb-°F in the temperature range from 32 to 78°F. This measured value compares favorably with USAELRDL estimates which are summarized in Figure 6. At a mean temperature of 55°F, a specific heat of 0.287 Btu/lb-°F is obtained from Figure 6.

2. Thermal Diffusivity

Tests were conducted in the calorimeter-dewar described above to determine the thermal diffusivity of Battery BA-270/U. The battery was instrumented with five thermocouples. Their locations are shown on Figure 7. The battery was encased in a thin plastic bag to prevent circulation or water within the interior sections of the battery during the test. The bag was evacuated slightly just prior to the test in order to "form fit" the plastic to the irregularities of the battery surface and insure good thermal conduction. The thermocouple leads were routed to the center and top of the battery so that they would not come in contact with the cooling water.

The tests consisted of first stabilizing the dewar and water temperature at 32°F by cooling with ice. An agitator was used to maintain uniformity of temperature during stabilization and testing.

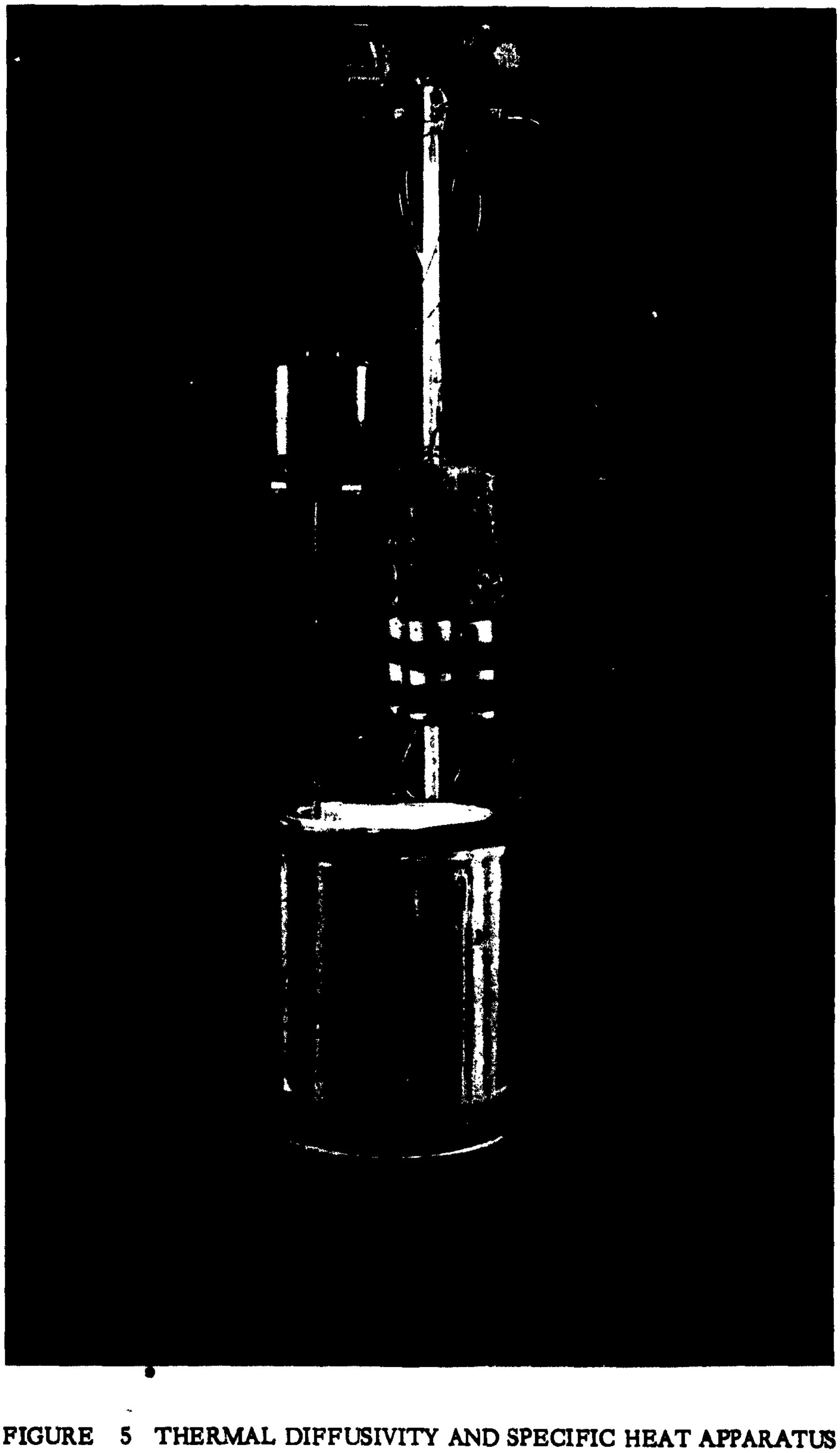


FIGURE 5 THERMAL DIFFUSIVITY AND SPECIFIC HEAT APPARATUS

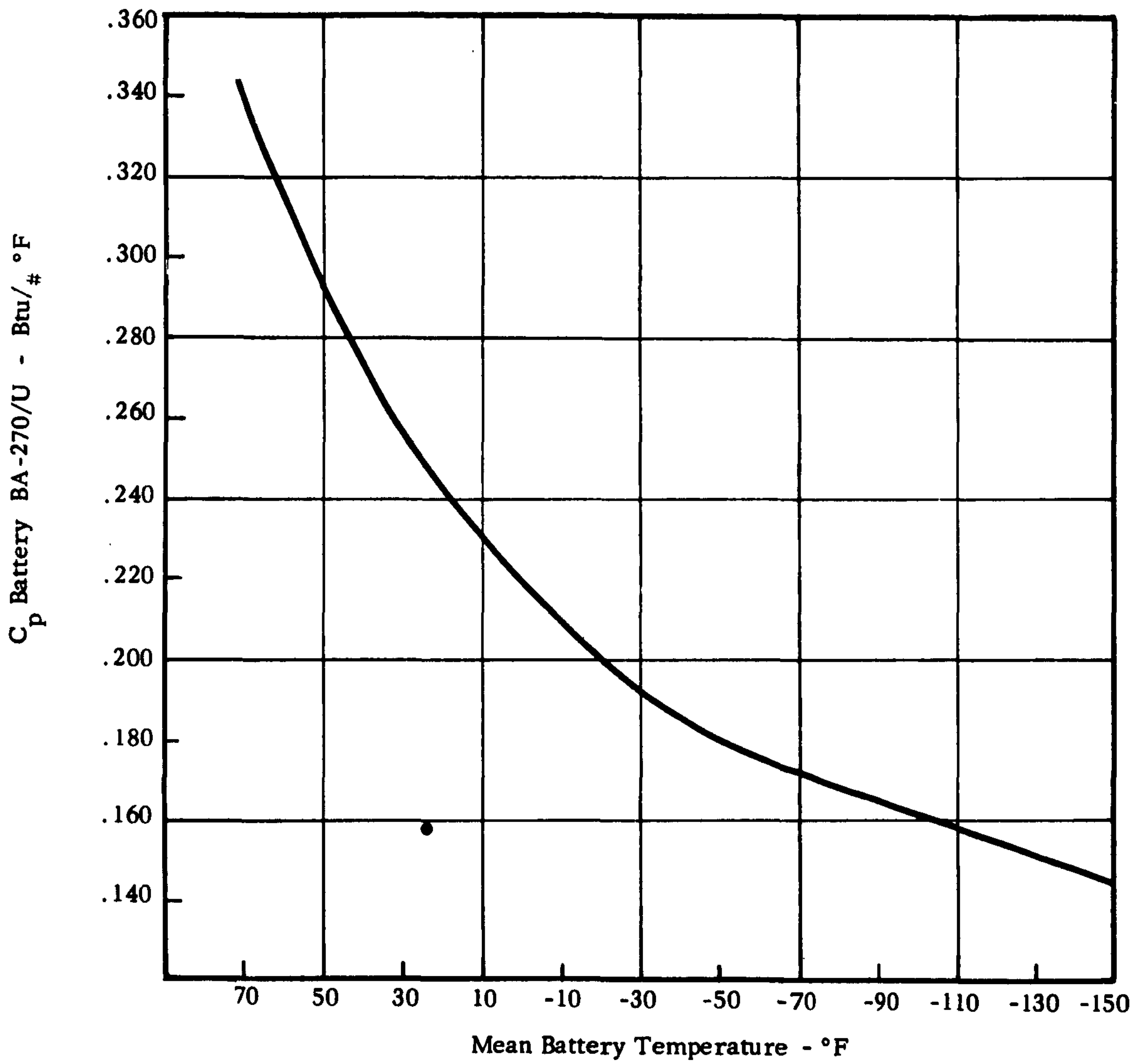
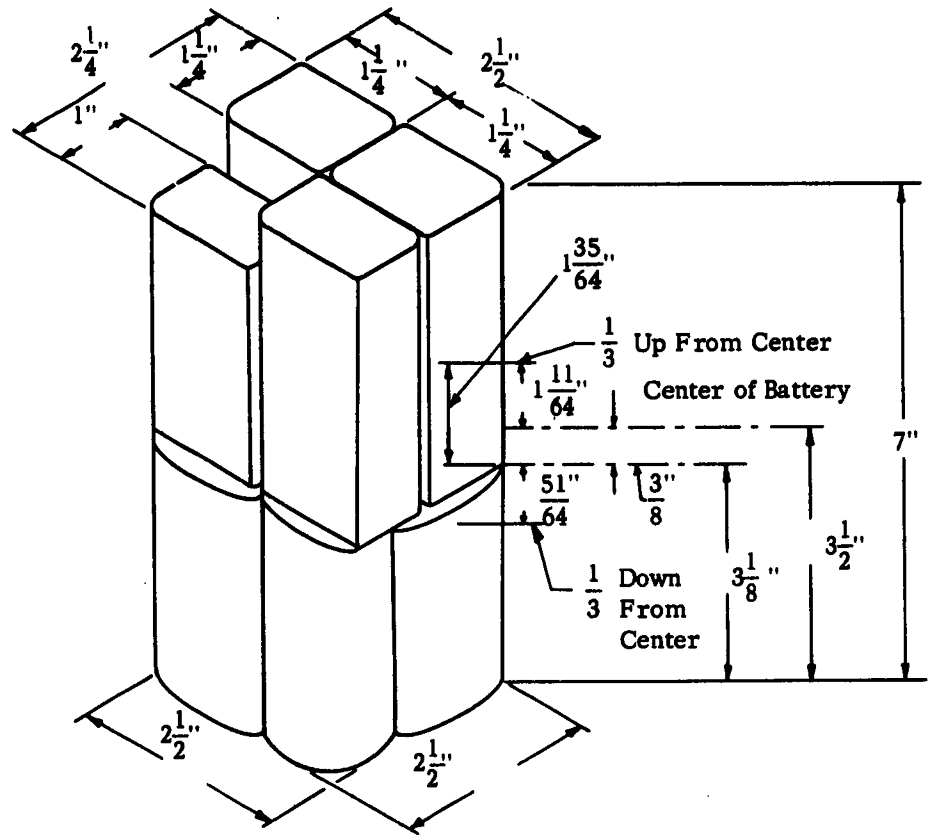
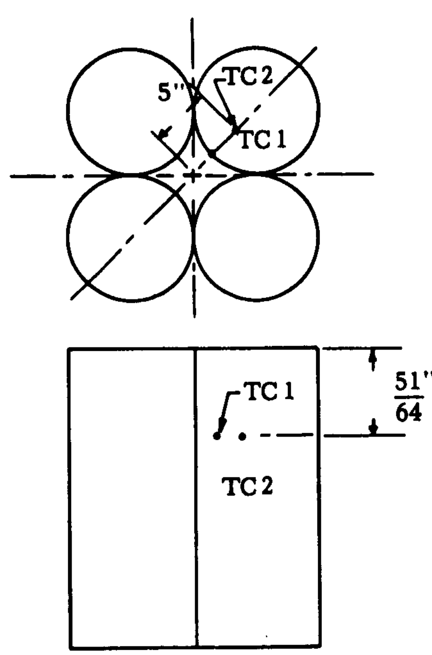


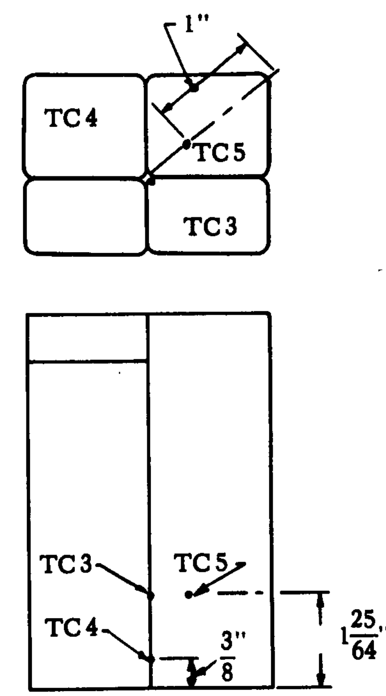
FIGURE 6 BATTERY SPECIFIC HEAT VS. BATTERY MEAN TEMPERATURE



Isometric of Battery BA-270/U



Bottom Section of Battery



Upper Section of Battery

FIGURE 7 BA-270/U BATTERY GEOMETRY AND THERMOCOUPLE LOCATION

The battery was allowed to stabilize at room temperature before immersing in the cold liquid. After the battery was immersed in the constant temperature bath, thermocouple readings were taken on a dual-channel Sanborn Model 297 millivolt recorder. Two thermcouples could be recorded at one time; several tests were performed. Results of the tests are shown in Figure 8. From the time-temperature curves, the thermal diffusivities were calculated by the method outlined in Carslaw and Jaeger.(1) The thermal diffusivity of the two sections of the battery were 0.0174 ft^2/hr for the "A" cell portion and 0.00735 ft^2/hr for the "B" cell portions. From these values, and measured specific heat and density, thermal conductivity was calculated. The thermal properties of the battery are summarized in Table II.

Table II

THERMAL PROPERTIES OF BA-270/U BATTERY

Specific Heat		0.285	Btu/lb-°F
Thermal Diffusivity	"A" section	0.0174	ft^2/hr
	"B" section	0.00735	ft^2/hr
Density	"A" section	117	lb/ft^3
	"B" section	123	lb/ft^3
Thermal Conductivity	"A" section	6.97	$\frac{\text{Btu-in}}{\text{ft}^2\,°\text{F hr}}$
	"B" section	3.10	$\frac{\text{Btu-in}}{\text{ft}^2\,°\text{F hr}}$

---

1. Carslaw, H.S. and J.C. Jaeger, "Conduction of Heat in Solids" Oxford Press, 1959, p. 185.

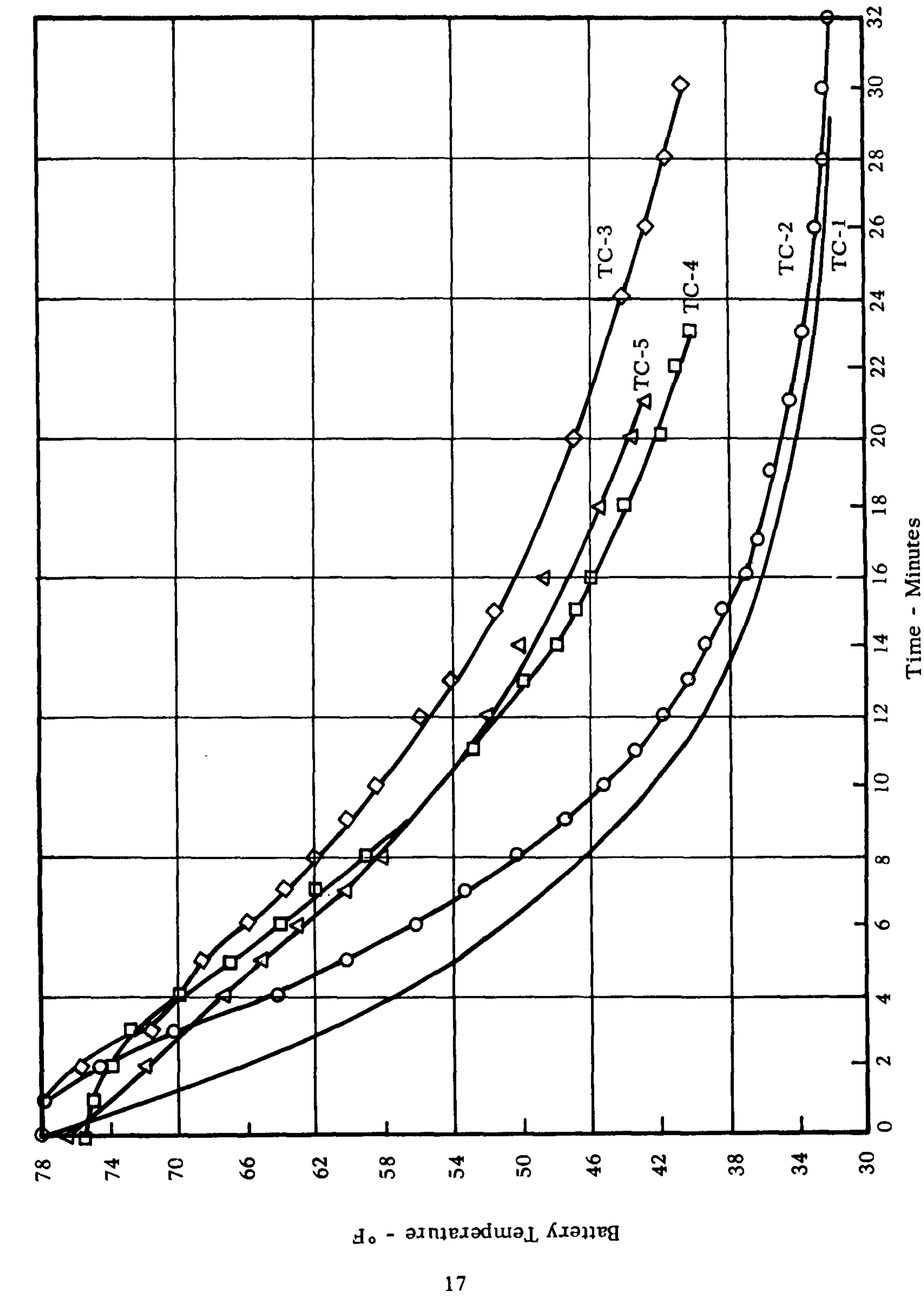


FIGURE 8 THERMAL DIFFUSIVITY, BATTERY COOL-DOWN PERFORMANCE

III

Analysis of Battery Insulation Systems

A. Battery Lead Heat-Leak

Steady-state heat losses from the battery through conduction along the battery leads were calculated.(2) In this analysis the heat conduction from the warm battery to the cold environment and the ohmic heating within the lead as a result of the current drain are considered. Minimum heat loss is achieved when no heat enters the warm end of the lead and the heat arriving at the cold end is all generated by the passage of current through the wire. This minimum heat loss as a function of current drain for each conduction path is shown in Figure 9. The total lead conduction loss is the sum of the losses for each battery lead. To minimize lead heat-leak, the lead length to cross section area must be optimized. Optimum lead designs as a function of current for three battery-to-ambient temperature differences are shown in Figure 10. For a constant lead length, it can be seen that the lead wire diameter will be a function of the current drain. This analysis indicates that the lead wires for the individual battery sections (A, B_1, B_2) should be of different diameters since the current requirements from these sections are not the same.

B. Mathematical Analysis of Thermal Performance of Batteries

In order to evaluate the performance of batteries operating under extreme environmental conditions, such as low ambient temperatures, battery temperature-time relationships must be known as a function of both fixed and variable parameters. Several characteristic parameters are: initial battery temperature; battery size, shape and thermal properties; type, thickness and thermal properties of protective insulation; ambient temperature and local convection heat transfer coefficients; location, type, and output of heating devices; duration of operation; and heat leaks into the battery-insulation-heater system.

---

2. McFee, R., "Optimum Input Leads for Cryogenic Apparatus," Rev. Sci. Inst. 30, 2, p. 98, February 1959.

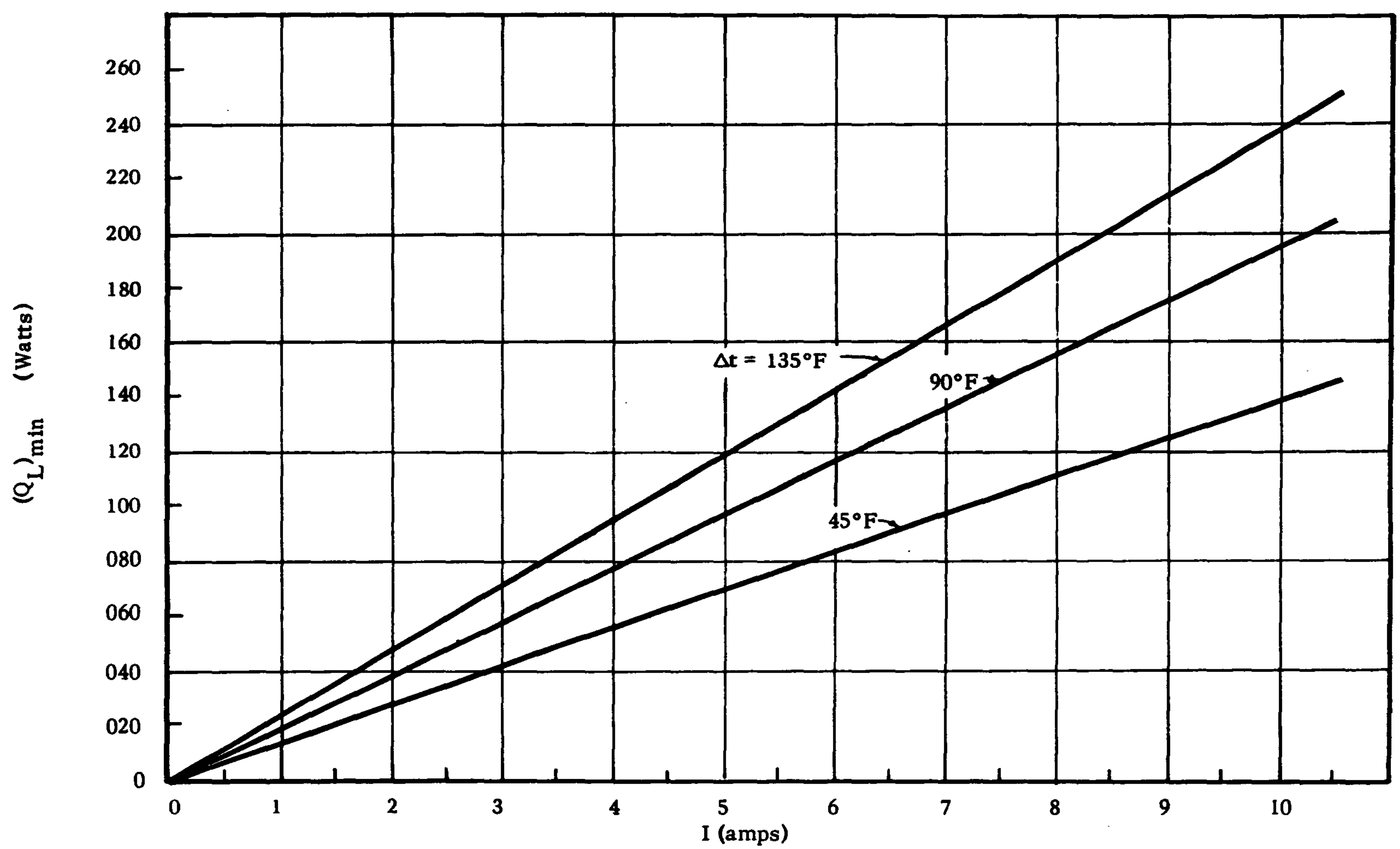


FIGURE 9 MINIMUM HEAT FLUX CORRESPONDING TO OPTIMUM LEAD DESIGN

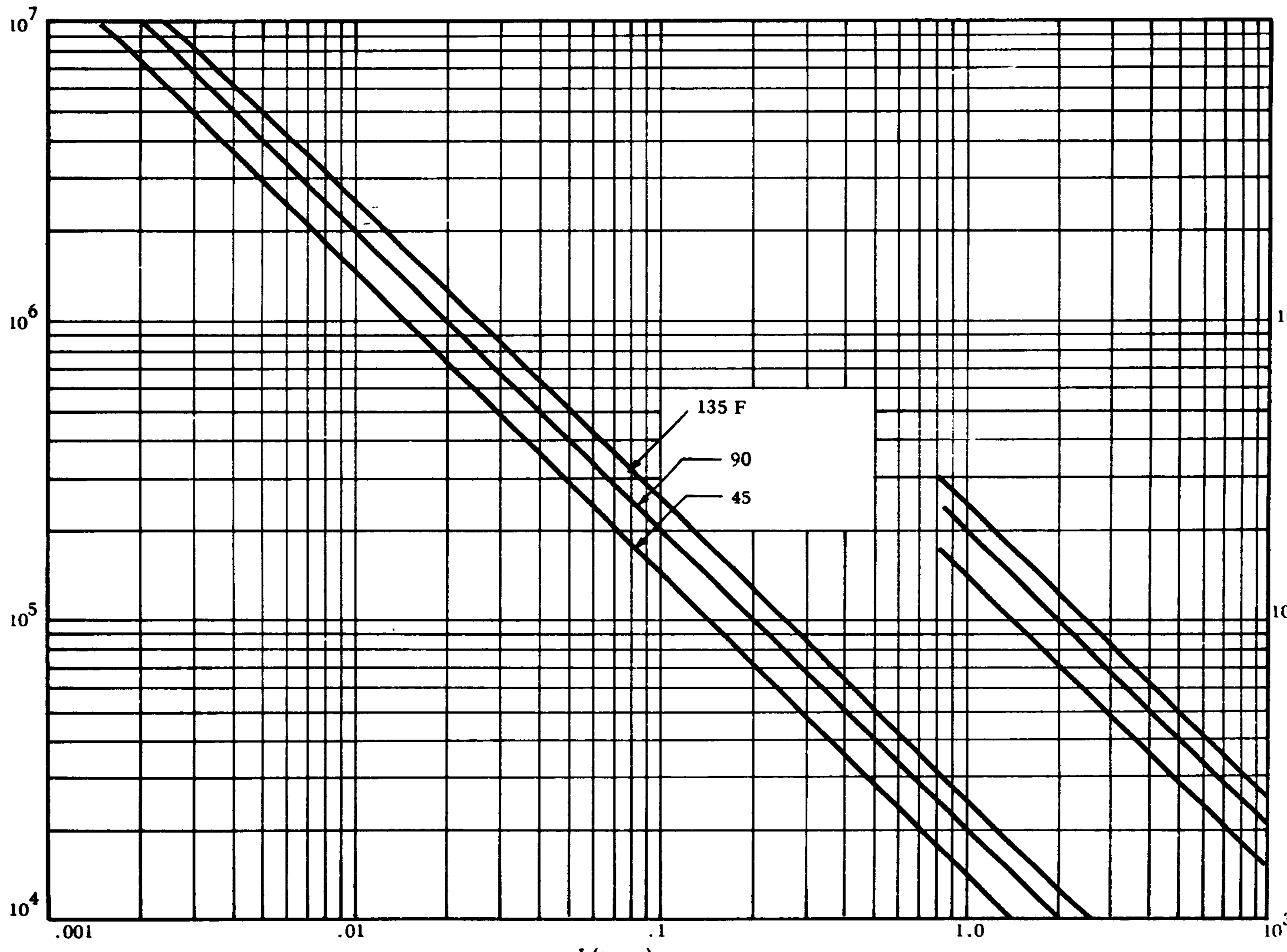


FIGURE [illegible] OPTIMUM LEAD DESIGNS CORRESPONDING TO MINIMUM HEAT LEAK

Two principal techniques are available for determining the thermal performance of battery assemblies: direct experimental measurements and computational analyses. In view of the many variables to be controlled and studied and the complexity of obtaining experimental data for the large number of conditions which require investigation, we have adopted a program of computational analysis to predict the thermal performance of batteries. Computational results will be verified with limited experimental data. A discussion of the analysis including the method of attack and the type of results anticipated is given below.

1. Computer Program

A program has been written for an IBM 7090 computer to determine the time-temperature history of a battery-heater-insulation system. The model used in the analysis is a rectangular homogeneous solid (the battery), surrounded by rectangular blocks of insulation material arranged to form rectangular surfaces parallel to the surfaces of the battery. The insulation thickness is uniform over the six battery surfaces.

Since the battery is assumed to be homogeneous, temperature distributions would be symmetric with respect to each plane which bisects the system and, thus, it is necessary only to calculate the temperature distributions in one-eighth of the system. The portion thus considered is further subdivided into eight zones, one in the battery and seven in the insulation. The system is divided so that each face of the zones has an area equal to that of the corresponding face of the adjacent zone. Equations are written for the heat flux across the face of any zone in terms of the average temperatures of the other faces of the zone and the mean temperature of the zone. The set of simultaneous equations which the computer solves inter-relates the heat flux equations thus derived.

The program has been written so that heaters on the battery surface and heat leaks (such as those along power leads) can be simulated and their effects on the temperature distribution in the battery-insulation system can be evaluated.

The parameters which are specified and those that can be varied in the computations are discussed below.

a. Battery Geometry -- In the initial calculations we chose the dimensions of the analytical model equal to those of the type BA-270/U battery. Justification of this choice is given by the opportunity to compare calculated and experimental results. The dimensions can be changed in later calculations.

b. Thermal Properties of Battery -- In our initial calculations, the thermal diffusivity, specific heat, and density of the battery portion of the analytical model were chosen equal to those measured in the laboratory for the type BA-270/U battery. These parameters can be varied if desired.

c. Insulation Thickness -- Insulation thicknesses of 1/2, 1 and 2 cm will be studied. These represent practical values with respect to the battery dimensions.

d. Thermal Properties of the Insulation -- Three sets of values for thermal conductivity, specific heat and density will be used corresponding to typical foam, evacuated powder, and evacuated multiradiation-foil insulations.

e. Ambient Temperatures -- Ambient temperatures of approximately 32, 0, -30 and -65°F will be used in the calculations.

f. Convection from Ambient to Battery Package -- A constant value of over-all heat transfer coefficient due to convection will be used in the calculations. This value was calculated from correlations presented in the literature. This value can be varied if desired to include the effects of high wind velocity or thermal radiation.

g. Initial Conditions -- The initial temperature of the battery and insulation system will be assumed to be uniform at 70°F.

h. Heat Input -- Three values of heater power will be used to simulate battery heating. The heat sources will be assumed to be uniformly distributed over the battery surfaces. Specific values of the heat source strength will be determined after the initial computer calculations with zero heat source strength.

i. Heat Leaks -- Several values of heat sources corresponding to heat leaks will be used. It will be assumed that the heat leak is directly connected to the average temperature of the battery. Specific values of the heat leak source strength will be determined after the initial tests.

In order to reduce the number of machine computations, only certain combinations of the variables and parameters listed above will be studied. The choice of combinations will be made to cover as wide a range of variables as is consistent with the possible practical use of systems corresponding to the analytical models. For example, if a computation is made using an insulation thickness of 2 cm, with no heater input or heat leaks, for an ambient temperature of -30°F, and if the results

indicate that the average temperature of the battery is below a specified operating temperature within an eight hour period, additional computations using lower ambient temperatures or smaller insulation thicknesses (other conditions being the same) would be unnecessary since acceptable battery performance could not be obtained. We would, however, consider smaller insulation thicknesses and lower ambient temperatures to determine necessary heater requirements for successful battery operation.

The results of the computer calculations will be organized to indicate heater requirements for given insulation types and thicknesses or the minimum insulation requirements for specified heater power. The relationships between these values and the ambient temperature will be studied. The effects of heat leaks due to current leads on the optimum insulation thicknesses and heater requirements will also be considered.

As a result of this parametric study, we will be able to determine the range of values of insulation, heater power, and heat leaks which will permit acceptable battery performance at various ambient temperatures. Calculations can be extended to other battery configurations with different geometrical and thermal properties if desired.

WORK PLANNED FOR THE NEXT QUARTER

In the next quarter, the battery, heater, and insulation information which has been generated in the course of the earlier work will be integrated in order to predict and compare the performance of the more attractive battery-heater-insulation systems as a function of temperature and for various mission lives.

The next quarter will be devoted to a parametric study of battery insulation systems. In this study, use will be made of an IBM 7090 computation program to investigate the effect of battery geometry and thermal properties, insulation thickness and thermal properties, and heat leaks. Ambient and initial conditions will be investigated as well as heat addition to the battery. Comparisons will be made wherever possible with experimental performance of existing battery insulation systems. Various methods for introducing heat to a battery in an insulated enclosure will be investigated.

As the parametric study progresses, we may find that additional battery-insulation configurations may need to be tested in our low temperature environmental chamber in order to check the analytically predicted performance.

RESEARCH AND DEVELOPMENT AREAS

As mentioned in our proposal, from time to time we will call the attention of the USAELRDL to certain directions uncovered by our work, in which further effort might be invested in order to improve the performance of low temperature batteries or to increase the understanding of the operation of electrochemical systems at low temperature.

Although there are considerable data on the low temperature performance of batteries we have found that much of this information could not be used because of its failure to specify the physical properties of the batteries studied or the details of the conditions of the tests. Mixtures or absence of units and of coordinates on graphical material have been further serious nuisances. We suggest that USAELRDL could very greatly facilitate its own work and that of its contractors if it would specify and strictly enforce a few simple rules for presenting battery performance data. Any effort on the part of USAELRDL in the direction of standardizing battery tests would be of additional value.

IDENTIFICATION OF KEY PERSONNEL

	Man-Hours
R. A. Horne, Project Director	343
I. A. Black, Assistant Project Director	120
D. L. Richardson, Senior Engineer (class 6)	65
R. P. Berthiaume, Senior Engineer (class 6)	290
D. A. Knapton, Senior Engineer (class 6)	80
L. W. Smith, Senior Engineer (class 6)	40
A. E. Wechsler, Senior Engineer (class 6)	40
J. F. Peterson, Shop Technician (class 8)	60
D. Coombs, Shop Technician (class 8)	140
J. J. Burke, Shop Technician (class 9)	45
	1223

DISTRIBUTION LIST
SECOND QUARTERLY REPORT
CONTRACT NO. DA36-039 SC-90706

	No. of Copies
Commanding Officer U.S.A. Electronics Research and Development Laboratory Fort Monmouth, N.J.	
ATTN: Logistics Division (MARKED FOR PROJECT ENGINEER)	2
ATTN: SELRA/P	1
ATTN: Dir of Research/Engineering	1
ATTN: File Unit #1	1
ATTN: Technical Document Center	1
ATTN: Technical Information Div (UNCLASSIFIED REPORTS ONLY FOR RETRANSMITTAL TO ACCREDITED BRITISH AND CANADIAN GOVERNMENT REPRESENTATIVES)	3
OASD (R&D), Rm 3E1065 ATTN: Technical Library The Pentagon Washington 25, D.C.	1
Chief of Research and Development OCS, Department of the Army Washington 25, D.C.	1
Commanding General U.S.A. Electronics Command ATTN: AMSEL-AD Fort Monmouth, N.J.	3
Director U.S. Naval Research Laboratory ATTN: Code 2027 Washington 25, D.C.	1

	No. of Copies
Commanding Officer and Director U.S. Naval Electronics Laboratory San Diego 52, California	1
Air Force Cambridge Research Laboratories ATTN: CRZC L. G. Hanscom Field Bedford, Massachusetts	1
Rome Air Development Center ATTN: RAALD Griffiss Air Force Base, N.Y.	1
Commanding General U.S.A. Electronics Research and Development Activity ATTN: Technical Library Fort Huachuca, Arizona	1
Commanding Officer Harry Diamond Laboratories ATTN: Library, Rm 211, Bldg 92 Connecticut Ave & Van Ness St., N.W. Washington 25, D.C.	1
Commanding Officer U.S.A. Electronics Material Support Agency ATTN: SELMS-ADJ Fort Monmouth, N.J.	1
Deputy President U.S.A. Security Agency Board Arlington Hall Station Arlington 12, Virginia	1
Commander Armed Services Technical Information Agency ATTN: TISIA Arlington Hall Station Arlington 12, Virginia	10

	No. of Copies
Chief U.S.A. Security Agency Arlington Hall Station Arlington 12, Virginia	2
Commander Aeronautical Systems Division ATTN: ASAPRL Wright-Patterson Air Force Base Ohio	1
Air Force Cambridge Research Laboratories ATTN: CRXL-R L. G. Hanscom Field Bedford, Massachusetts	1
Headquarters U. S. Army Materiel Command Research and Development Directorate ATTN: AMCRD-DE-MO Washington 25, D.C.	1
Commanding General U.S.A. Electronics Command ATTN: AMSEL-RE-A Fort Monmouth, N.J.	1
Commanding General U.S.A. Combat Developments Command ATTN: CDCMR-E Fort Belvoir, Virginia	1
Commanding Officer U.S.A. Communications and Electronics Combat Development Agency Fort Huachuca, Arizona	1
Director Fort Monmouth Office U.S.A. Communications and Electronics Combat Development Agency Fort Monmouth, N.J.	1

	No. of Copies
Air Force Systems Command Scientific/Technical Liaison Office U.S. Naval Air Development Center Johnsville, Pennsylvania	1
Corps of Engineers Liaison Office U.S.A. Electronics Research and Development Laboratory Fort Monmouth, N.J.	1
Marine Corps Liaison Office U.S.A. Electronics Research and Development Laboratory Fort Monmouth, N.J.	1
AFSC Scientific/Technical Liaison Office U.S.A. Electronics Research and Development Laboratory Fort Monmouth, N.J.	1
Power Information Center Moore School Bluiding 200 South Thirty-Third Street Philadelphia 4, Pennsylvania	1

PSD Dist List B (Steering Group
Members - Mandatory)
January 1963

DISTRIBUTION LIST
SECOND QUARTERLY REPORT
CONTRACT NO. DA36-039 SC-90706

	No. of Copies
Dr. Sidney J. Magram Physical Sciences Division Army Research Office 3045 Columbia Pike Arlington, Va.	1
Dr. Ralph Roberts Head, Power Branch Office of Naval Research (Code 429) Department of the Navy Washington 25, D.C.	1
Mr. Bernard B. Rosenbaum Bureau of Ships (Code 340) Department of the Navy Washington 25, D.C.	1
Mr. George W. Sherman Aeronautical Systems Division ATTN: ASRMFP Wright-Patterson Air Force Base Ohio	1
Dr. John H. Huth Advanced Research Projects Agency The Pentagon, Room 3E157 Washington 25, D.C.	1
Lt. Col. George H. Ogburn, Jr. Auxiliary Power Branch (SNAP) Division of Reactor Development U.S. Atomic Energy Commission Washington 25, D.C.	1

	No. of Copies
Mr. Walter C. Scott National Aeronautics & Space Administration 1520 H Street, N.W. Washington 25, D.C.	1
Institute for Defense Analysis 1666 Connecticut Avenue, N.W. Washington 25, D.C.	
ATTN: Dr. George Szego	1
ATTN: Mr. Robert Hamilton	1

DISTRIBUTION LIST
SECOND QUARTERLY REPORT
CONTRACT NO. DA36-039 SC-90706

	No. of Copies
Bright Star Industries 600 Getty Avenue Clifton, N.J. ATTN: Mr. F. Keller	1
Mallory Battery Company Tarrytown New York ATTN: Mr. J. Dalfonso	1
Burgess Battery Company Freeport Illinois ATTN: Mr. M. Wilke	1
Union Carbide Consumer Products Co. Cleveland Ohio ATTN: Dr. F. Granger	1
Electric Storage Battery Company Ray-O-Vac Division 212 East Washington Avenue Madison 10, Wisconsin ATTN: Mr. P. Albert	1
Marathon Battery Company Wausau Wisconsin ATTN: Mr. G. Schroeder	1
Radio Corporation of America Somerville New Jersey ATTN: Dr. G. Lozier	1

A.D. ______________ Accession No. ______

UNCLASSIFIED

Arthur D. Little, Inc., Cambridge 40, Massachusetts

Low Temperature Operation of Batteries by R.A. Horne and I.A. Black

15 November 1962 to 14 February 1963, pp. 51, Illustrations 10, Tables 2
Third Quarterly Progress Report
Signal Corps Contract No. DA36-039-SC-90706
Department of Army Project 3A99 09-002-02

Reported values for watt-hr/lb, in^3/lb, and $/lb have been assembled for primary and secondary batteries for the temperature range +70 to -65°F. The specific heat and thermal diffusivity of the BA-270/U battery has been measured. The heat leak through electrical leads has been analyzed. A computer program has been prepared for calculating the time-temperature history of battery-heater-insulation systems.

UNCLASSIFIED

A.D. ______________ Accession No. ______

UNCLASSIFIED

Arthur D. Little, Inc., Cambridge 40, Massachusetts

Low Temperature Operation of Batteries by R.A. Horne and I.A. Black

15 November 1962 to 14 February 1963, pp. 51, Illustrations 10, Tables 2
Third Quarterly Progress Report
Signal Corps Contract No. DA36-039-SC-90706
Department of Army Project 3A99 09-002-02

Reported values for watt-hr/lb, in^3/lb, and $/lb have been assembled for primary and secondary batteries for the temperature range +70 to -65°F. The specific heat and thermal diffusivity of the BA-270/U battery has been measured. The heat leak through electrical leads has been analyzed. A computer program has been prepared for calculating the time-temperature history of battery-heater-insulation systems.

UNCLASSIFIED

A.D. ______________ Accession No. ______

UNCLASSIFIED

Arthur D. Little, Inc., Cambridge 40, Massachusetts

Low Temperature Operation of Batteries by R.A. Horne and I.A. Black

15 November 1962 to 14 February 1963, pp. 51, Illustrations 10, Tables 2
Third Quarterly Progress Report
Signal Corps Contract No. DA36-039-SC-90706
Department of Army Project 3A99 09-002-02

Reported values for watt-hr/lb, in^3/lb, and $/lb have been assembled for primary and secondary batteries for the temperature range +70 to -65°F. The specific heat and thermal diffusivity of the BA-270/U battery has been measured. The heat leak through electrical leads has been analyzed. A computer program has been prepared for calculating the time-temperature history of battery-heater-insulation systems.

UNCLASSIFIED

A.D. ______________ Accession No. ______

UNCLASSIFIED

Arthur D. Little, Inc., Cambridge 40, Massachusetts

Low Temperature Operation of Batteries by R.A. Horne and I.A. Black

15 November 1962 to 14 February 1963, pp. 51, Illustrations 10, Tables 2
Third Quarterly Progress Report
Signal Corps Contract No. DA36-039-SC-90706
Department of Army Project 3A99 09-002-02

Reported values for watt-hr/lb, in^3/lb, and $/lb have been assembled for primary and secondary batteries for the temperature range +70 to -65°F. The specific heat and thermal diffusivity of the BA-270/U battery has been measured. The heat leak through electrical leads has been analyzed. A computer program has been prepared for calculating the time-temperature history of battery-heater-insulation systems.

UNCLASSIFIED